LOW RF LOSS CONDUCTIVE CERAMIC FOR HIGH POWER INPUT COUPLER WINDOWS FOR SRF CAVITIES

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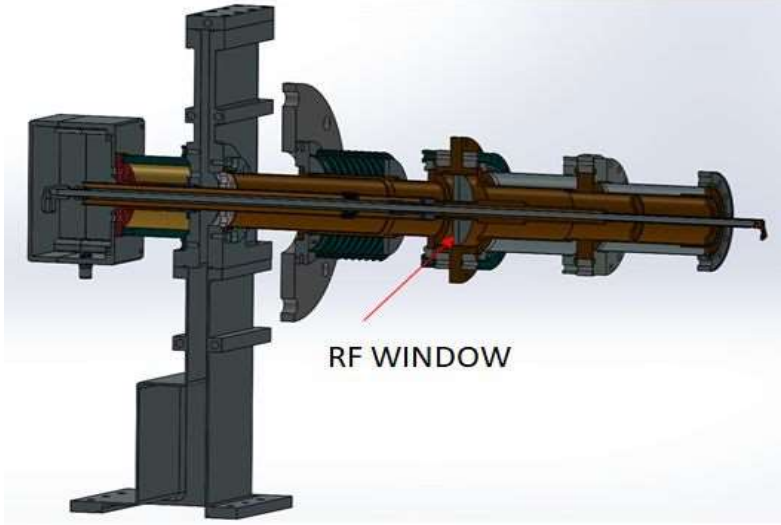
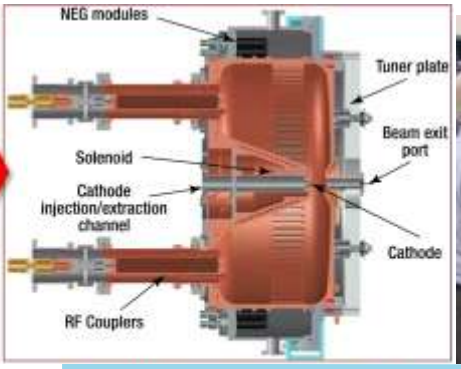
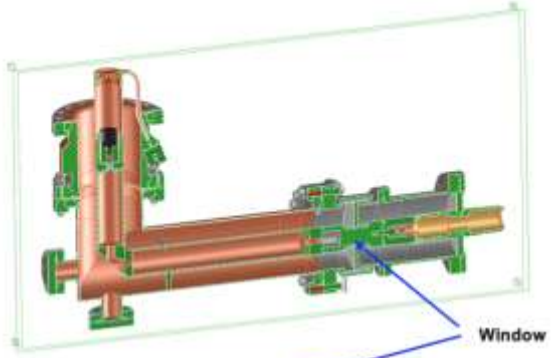
A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

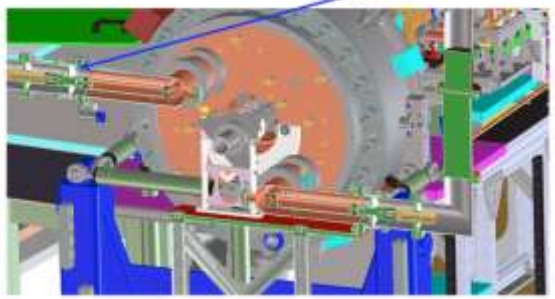
Motivation

- High power RF couplers connect transmission lines to cavities, providing power used to accelerate particle beam
- Coupler also provides vacuum barrier for beam vacuum via RF windows
- RF windows experience breakdown at much lower voltages than comparable insulators in DC fields
- For large voltages, electron emission from “triple junction” and multipacting lead to window failure due to arching and/or thermal runaway
- These processes are major problem for RF windows and couplers; responsible for damage and lost beam time in SRF cavity and cryomodule operation





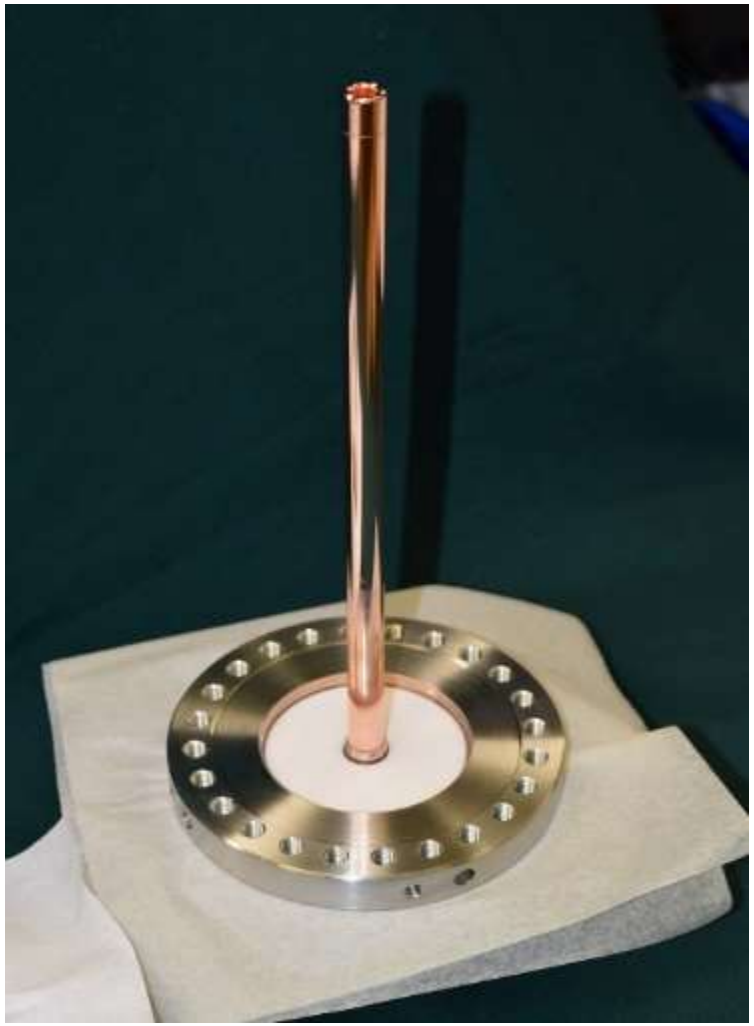




- Example: the Advanced Photoinjector Experiment’s VHF gun and in the LCLS-II injector
- Window was broken: charging because of the direct line of sight for the beam
- A new 90-degree coupler will keep ceramic vacuum window out of harm’s way

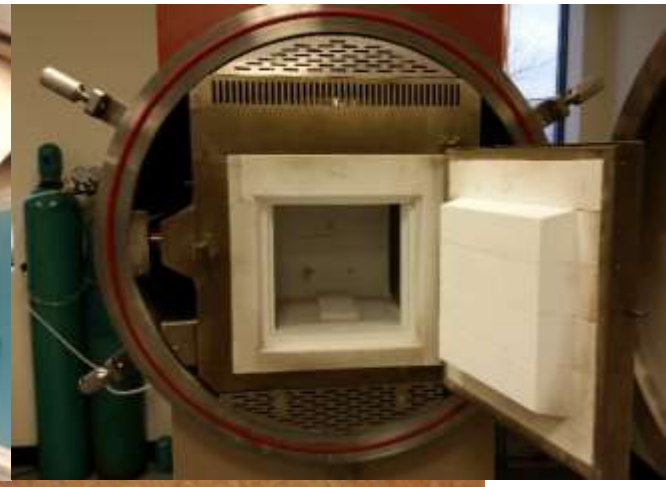
A Solution

- *Mitigate charge accumulation on RF windows by using a conductive ceramic that avoids the need for complicated geometry and/or surface coatings*
- Euclid has developed a Mg-Ti oxide based ceramic with finite DC electrical conductivity and low loss tangent
- Collaboration with national labs (JLab, Fermilab, Brookhaven, CERN) on design and fabrication methods
- Incorporation into high power couplers ongoing
  - Brazing of first set of couplers almost complete



Fabrication and Sintering of MgTi Conductive Ceramic

- Euclid fabricated the MgTi ceramic elements with:
  - Increased conductivity from 10^{-12} to 10^{-8} S/m
  - Relative dielectric constants ε_r=15
  - Figure of merit, Q × f [GHz], in the range 30,000–120,000, providing tan δ ~ 10^{-5} @ 650 MHz
- Electrical and microwave properties of ceramic window components optimized via sintering process

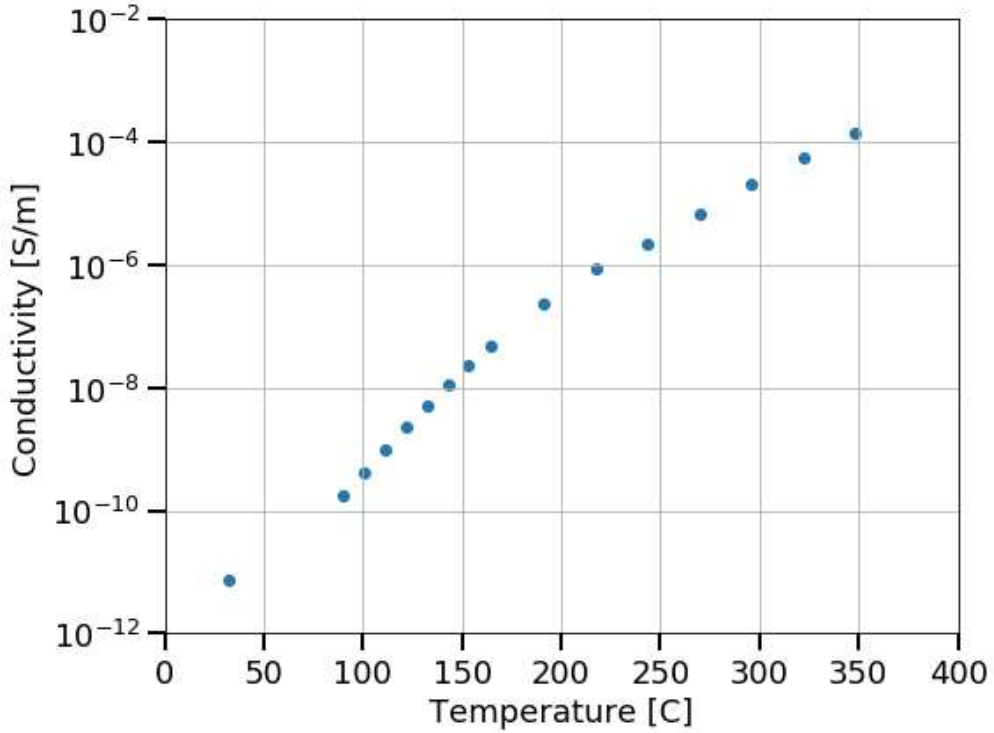


5.2x10^-6	5.5x10^-6	5.6x10^-6
1.0x10^-5	1.9x10^-5	2.1x10^-5

tan δ at 650 MHz

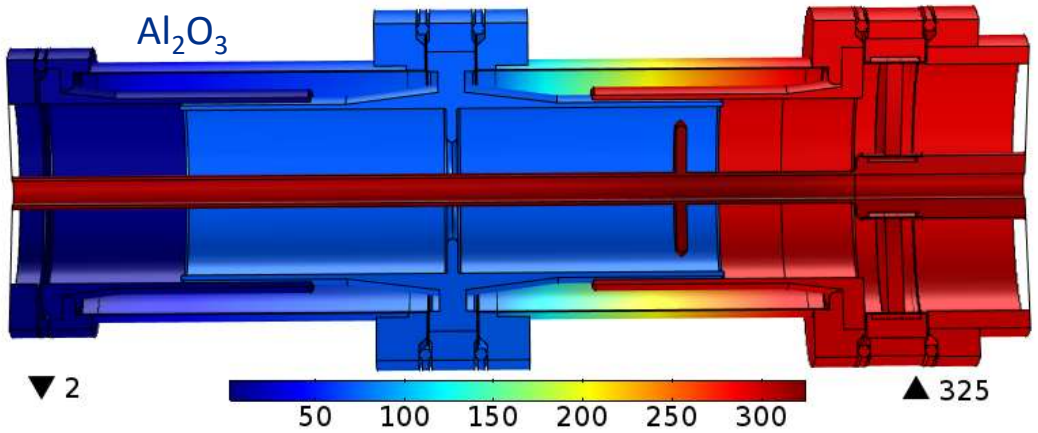
Temperature Dependence

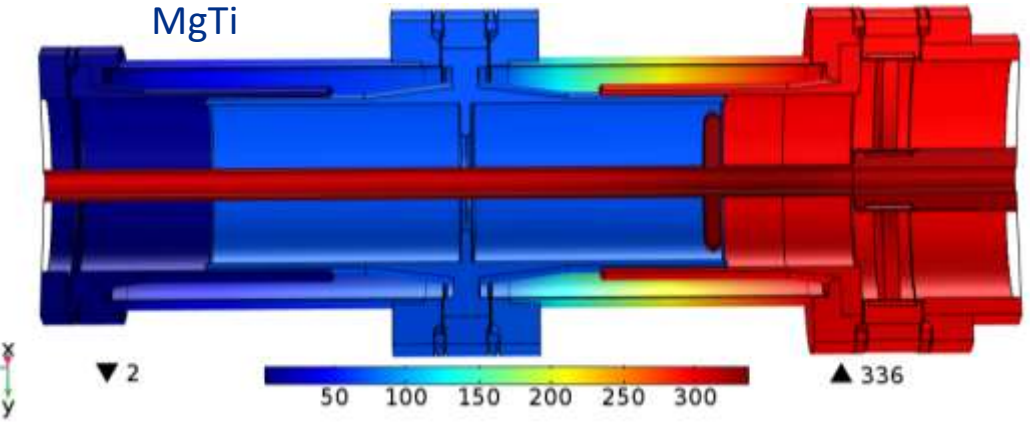
- Conductivity and loss tangent measured over wide temperature range
- Conductivity increased >100x between room temperature and 100°C
- Loss tangent decreased only 20%
- *Natural benefit of temperature rise during operation is increased conductivity*

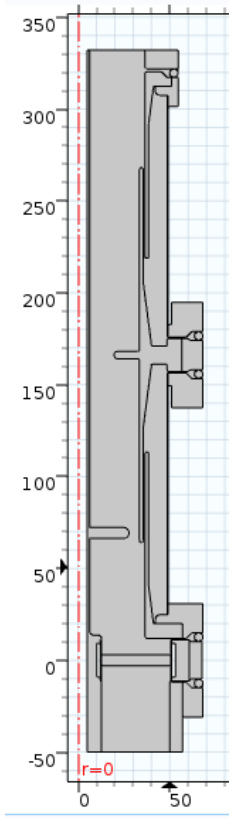


Electrodynamic & Thermomechanical Modelling

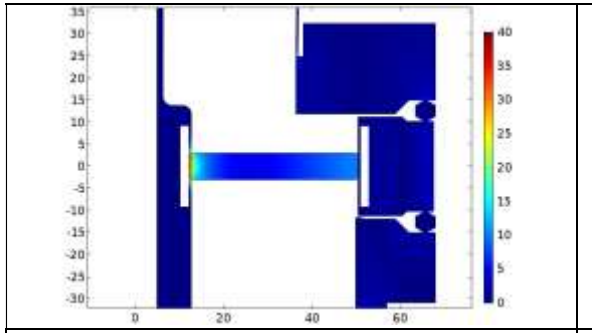
- Thermomechanical simulations (100 kW CW input power) show slightly worse performance than alumina, but still within acceptable range



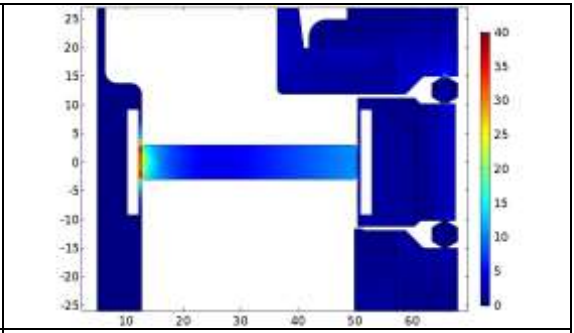




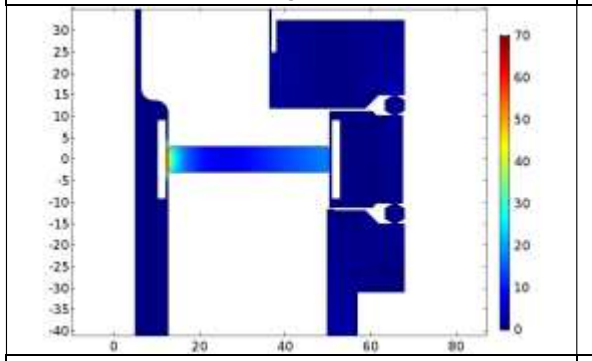
Stress Distribution (MPa)



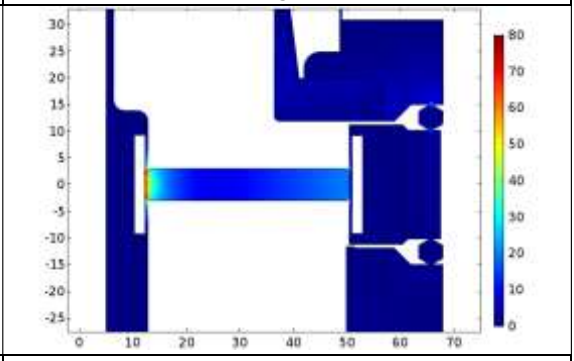
Al_2O_3 ver 1



Al_2O_3 ver 2



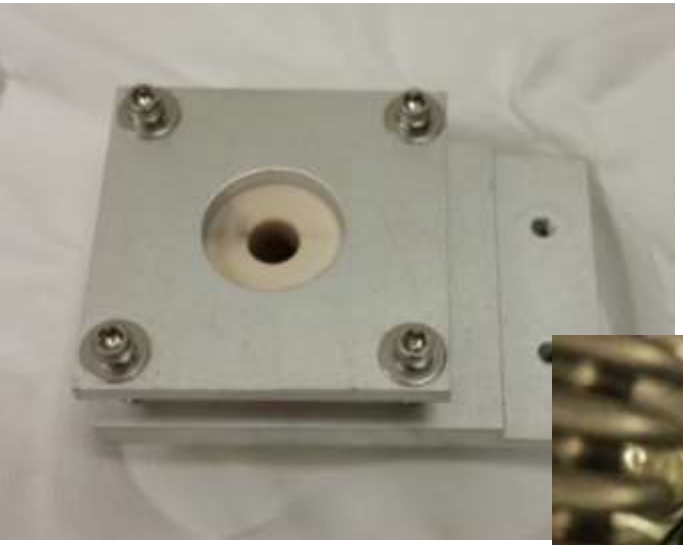
MgTi ver 1

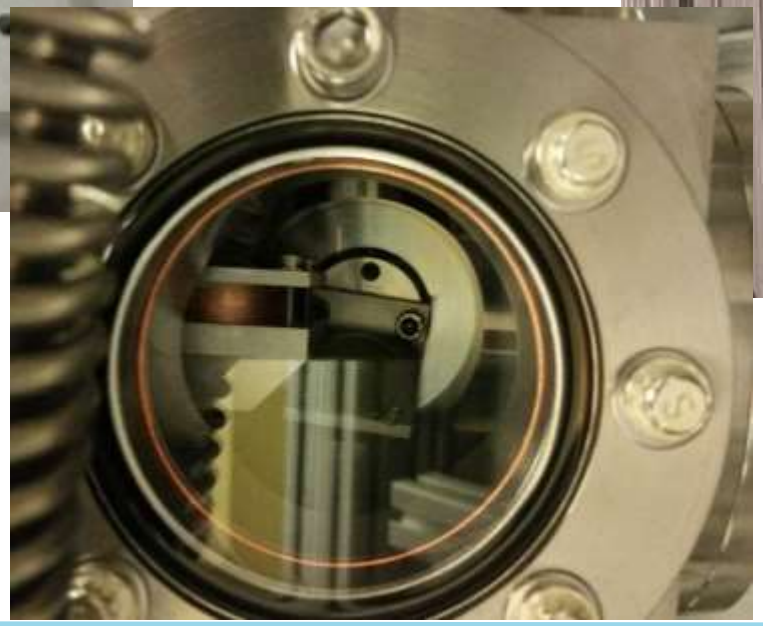


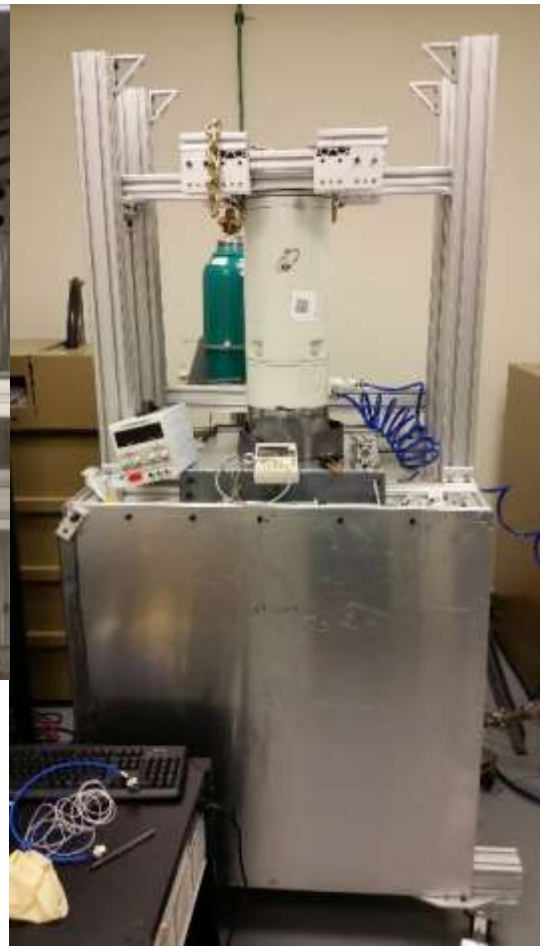
MgTi ver 2

Beam Charging Test

- Charging/discharging of both conductive and non-conductive ceramic measured with DC electron beam

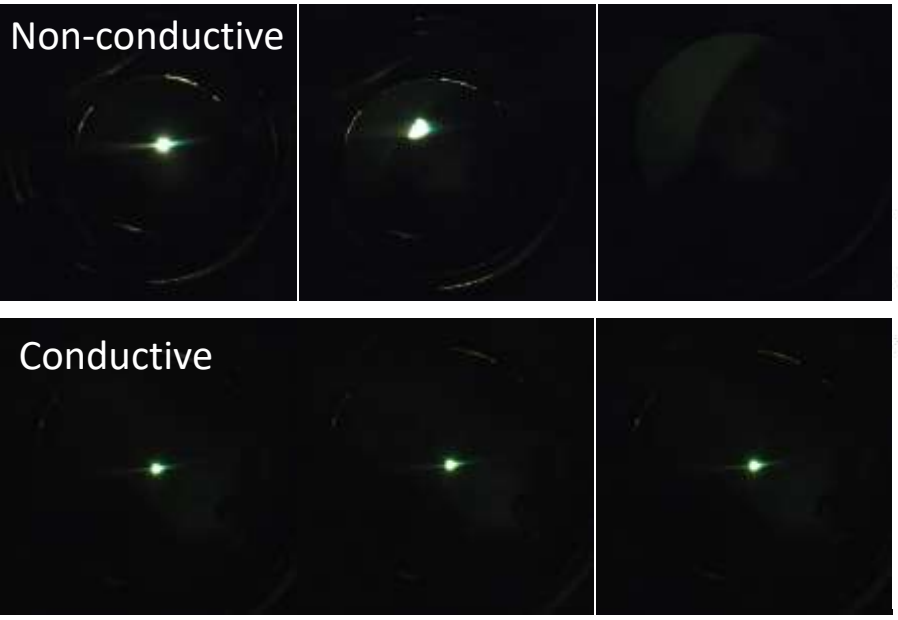


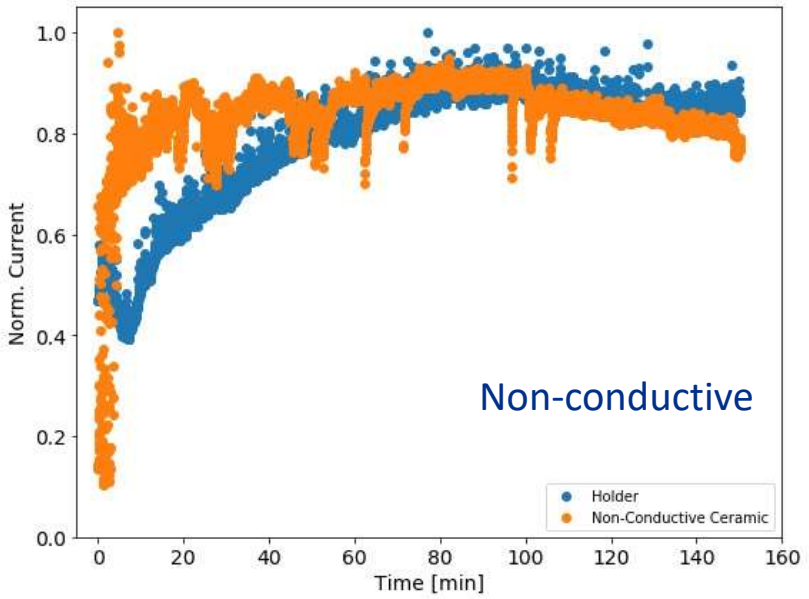


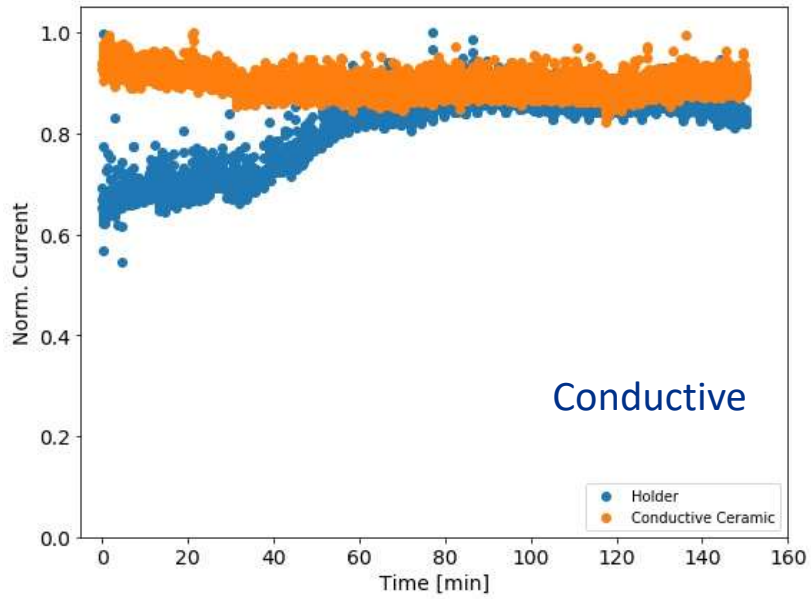


Beam Charging Results

- Ceramics subject to DC electron beam for 2.5 hours
- Beam sent through hole in ceramic (photos), impacting ceramic (orange data points), & impacting metal holder (blue data points)
- *Conductive ceramic effectively discharges DC electron beam directly impinging on surface*

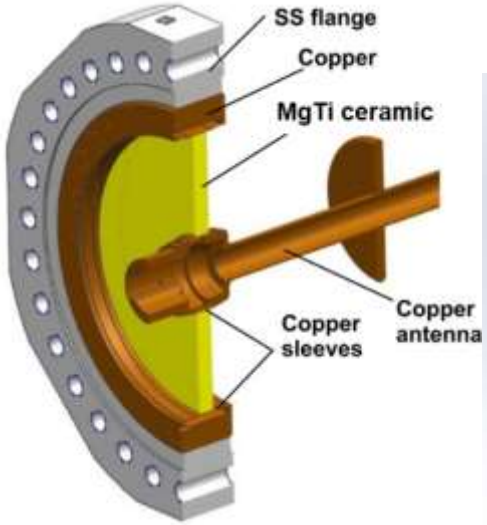


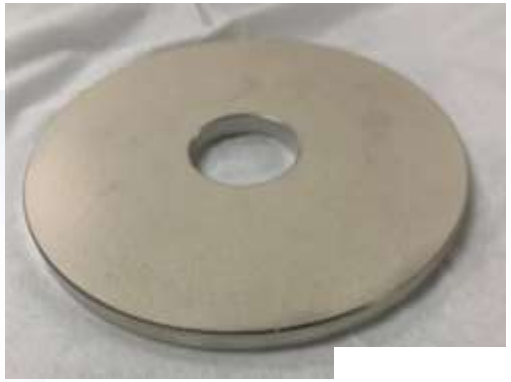


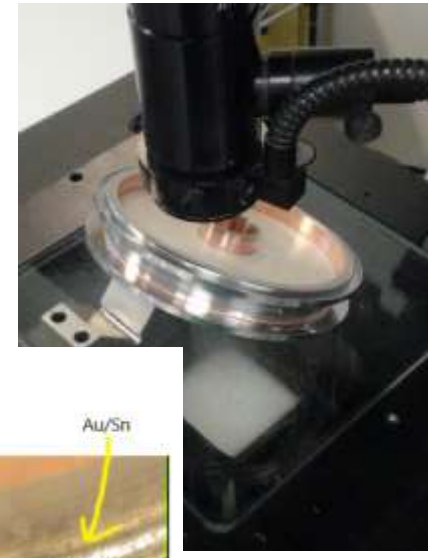


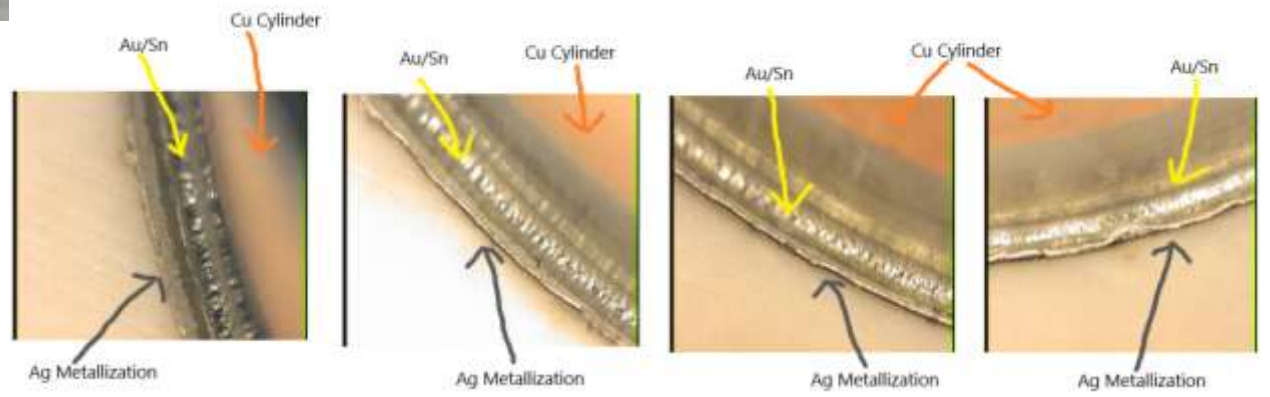
Brazing Technology Development – I

- Initial braze procedure utilized low temperature Au-Sn alloy with Ag metallized ceramic
- Inner braze joint leaked; Ag pulled back from ceramic during cooldown



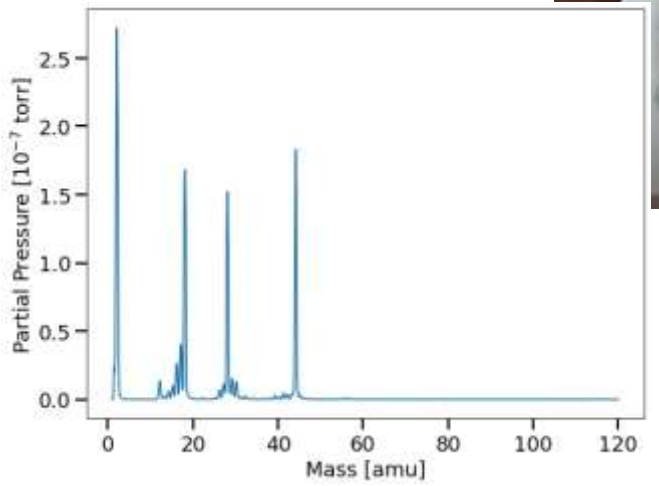






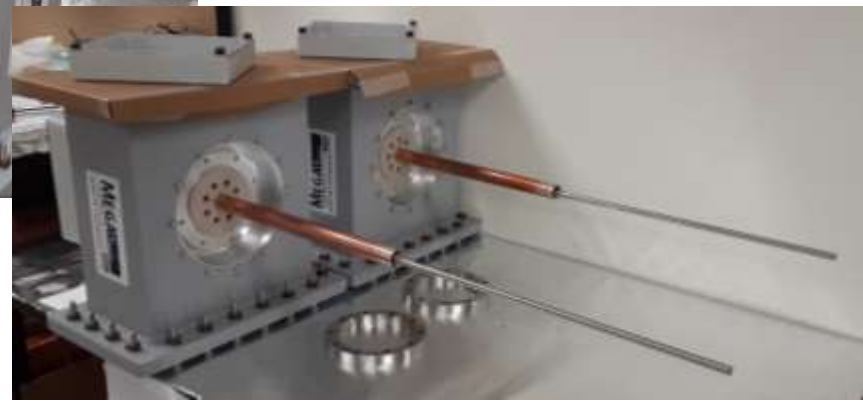
Brazing Technology Development – II

- Alternative brazing approaches considered:
  - Cu sputtering/electroplating
  - S-Bond solder, 250 C, Sn-Ag-Ti-Mg
    - First bonding attempt vacuum leak-tight
    - No detectable contaminants in RGA scan at 3×10^{-8} torr
- *Likely brazing solution identified:*
  - *Active braze alloy (Cu-Ag, ≈740 C)*
  - *Couplers using windows recovered from first braze iteration in progress*



High Power Test at Fermilab

- High power tests of multiple couplers planned:
  - 1st with non-conductive MgTi window for Dec. 2020
  - 2nd with conductive MgTi window mid-2021
- Replacement of several components nearly complete



Summary

- New, conductive ceramic aimed at alleviating charging problems with conventional RF windows
- Conductivity and RF loss of ceramic controllable, beneficial temperature dependence
  - Conductivity 100-1000x that of conventional ceramics
  - Loss tangent 10^{-5} – 10^{-4} in the 100 MHz – 10 GHz range
- Brazing procedure that produces a robust braze joint while preserving ceramic properties identified
  - First, control, couplers in production
  - Optimized brazing procedure for second, conductive couplers in progress
- First high power test of conductive ceramic couplers to take place at Fermilab winter 2020-2021
- First high power test of conductive ceramic windows at JLab scheduled for mid-2021

Acknowledgement

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- Our collaborators
  - Fermilab: Sergey Kazakov, Nikolay Solyak
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  - CERN: Erk Jensen, Eric Montesinos
  - Penn State University: Michael Lanagan, Steve Perini
  - Ceramic Ltd.: Elizabeta Nenasheva